

Editorial Manager(tm) for Journal of Physics: Conference Series
Manuscript Draft

Manuscript Number:

Title: ADVANCES IN PROPOSED D-CLUSTER INERTIAL CONFINEMENT FUSION TARGET

Article Type: Oral

Corresponding Author: George Miley,

Corresponding Author's Institution:

First Author: George H Miley

Order of Authors: George H Miley; Xiaoling Yang; Heinrich Hora; Kirk Flippo; Sandrine Gaillard; Dustin Offermann; Cort Gautier

ADVANCES IN PROPOSED D-CLUSTER INERTIAL CONFINEMENT FUSION TARGET

George H. Miley,¹ Xiaoling Yang,¹ Heinrich Hora,² Kirk Flippo,³ Sandrine Gaillard,³ Dustin Offermann,³ and Cort Gautier³

¹Department of Nuclear, Plasma and Radiological Engineering, University of Illinois, Urbana, IL 61801 USA; ²Department of Theoretical Physics, University of New South Wales, Sydney, Australia; ³Plasma Physics Group, Los Alamos National Laboratory Los Alamos, NM 87545 USA

ghmiley@uiuc.edu

Abstract. Our recent research has developed a technique for imbedding ultra high density deuterium “clusters” (D cluster) in Palladium (Pd) thin film. Experiments have shown that in Pd these condensed matter state clusters approach metallic conditions, exhibiting superconducting properties. This deuterium cluster is achieved through electrochemically loading-unloading deuterium into a thin metal film, such as Palladium (Pd). During the loading process, Palladium lattice expands significantly due to invasion of deuterium into the interstitial sites. With the large enough stress, some linear lattice imperfections, called dislocations, form at α/β transformation interface. These dislocation defects form a strong potential trap causing deuterium to condense. In the present study, a new method employing nano-structuring of the Pd is proposed to significantly improve the site density over the target volume, suggesting that a sizable region of the compressed target deuterium can reach densities an order of magnitude higher than possible with prior target designs. This improved cluster packing fraction will enable a significant increase of the fusion reaction burn density, hence the target burn-up efficiency.

1. Introduction

Current state-of-the-art ICF target technology employs cryogenic D-T filled targets. The targets are expensive and complex, requiring several hours of laser heating and cooling cycles and tritium decay smoothing during preparation. While such operation appears feasible for single shot experiments, the extension to rapid pulsing and later to low cost commercial target manufacture and delivery may be a show stopper for useful ICF power. Clearly a non-cryogenic design is a key goal to seek.

Recent SQUID measurement has shown ultra-dense states of deuterons with many more than 100 deuterons within a crystal defect in a palladium crystal are possible, and a superconductive state of these clusters was demonstrated in these experiments [1, 2]. Similar ultra-dense state of deuterons was seen at surface defects of iron oxide resulted in ion energies of 630 eV through Mass spectrometry measurements [3]. It may well be assumed that both cluster states are of the same nature though the states are concentrated at the surface in the iron oxide case due to the catalytic generation in contrast to the Pd samples with localization in the bulk volume [2]. In both cases their existence was confirmed by the LENR process [4] which likewise should be valid including when an inverted Rydberg state is present. A very important application would be using these clusters to achieve non-cryogenic targets

for inertial confinement fusion. In principle this could also provide a compressed fuel density up to about 1000 times solid state density. [2][5][6].

2. Formation of Ultra-High-Density Deuterium Cluster in Palladium Foil

To date, we have demonstrated more than 100 deuterons located in the dislocation loops of Palladium thin film at room temperature. [1, 2] This high density deuterium cluster is achieved through electrochemically loading-unloading H/D into a thin metal film, such as Palladium (Pd). During the loading process, metal lattice expands significantly due to invasion of H/D into the interstitial sites. The Palladium lattice expands from 3.889Å to 3.894Å (α -phase) when hydrogen is physically adsorbed (PdH_{0.015}), and then further to 4.025Å (β -phase) when chemical bonding is formed (PdH_{0.6}). With the large enough stress, some linear lattice imperfections, called dislocations (Figure 1), form at α/β transformation interface. The diameter of the dislocation defects is around 2 burgers factor, and the length of them depends on the dimensions of the Palladium film. After loading, the loosely bonded hydrogen is unloaded by applying positive current to metal film, while the formed cluster materials remain in place due to their high binding energy. Additional dislocations and clusters are formed upon reloading. Thus this loading and unloading process is repeatedly done in order to achieve abundant and uniform distribution of dislocation loops. After about 6-10 cycles, the packing fraction of clusters saturates.

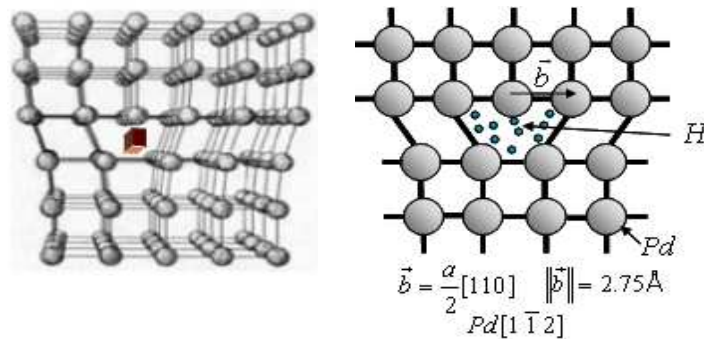


Figure 1 Scheme of edge dislocation loops in Pd containing condensed H/D.

The following experiment results briefly described the evidence of the UHD H clusters:

I. Temperature Programmed Desorption (TPD) Analysis

TPD involves heating a sample while contained in a vacuum and simultaneously detecting the residual gas in the vacuum by means of a mass analyzer. This results in a peak in the pressure versus time plot. The binding energy of the bound species and the total hydrogen desorbed could be calculated from the recorded curve. In our TPD experiment, the sample was heated from 20 °C to 700 °C in baseline vacuum of 10^{-8} Torr (Figure 3). The calculated binding energy of H/D based on the Garlick-Gibson model is estimated as 0.65 ± 0.10 eV, which is consistent with the result of Kirchheim for hydrogen trapping at dislocation core sites in cycled Pd. Thus, with known dislocation density $2 \times 10^{11} \text{ cm}^{-2}$, the local concentration of hydrogen within dislocation loops is calculated to be $[\text{H}]/[\text{Pd}] \sim 1.8$.

II. Superconductivity measurement

Another proof of the existence of UHD D cluster is its demonstrated superconductive properties in direct resistance measurement and SQUID measurement. After eliminating the temperature-independent part of resistance caused by dislocation formation, cluster material showed much lower resistance than pure Pd. This enhanced conductivity is best seen in the ratio of resistances – the larger temperature coefficient for the Pd:H cluster sample is an indication of a more metal-like behavior. Both the reduced resistance and enhanced temperature coefficient are attributed to condensation of hydrogen into a metal-like phase at dislocation cores. [1]

3. New Nano-Structure Film (NSF) Electrodes/Targets

Recently, a new type of electrode, the nano-structured film (NSF) electrode, was developed to create cluster formation in nanostructures manufactured on a Pd or Ni thin film electrode. The concept is to mimic the dislocation loops, but achieve a larger volumetric concentration or “packing fraction” than in the previous electrodes. This method used follows one originally developed by R.N. Rhonda of the International Nickel Plating Company. SEM image of plated Pd on Ni Microfelt or Ni foam are shown in Figure 2. The structures provided are thought to provide the conditions needed for cluster formation. Some preliminary electrolytic studies have been encouraging, but much more needs to be studied to understand the true promise of this new electrode design. If high volumetric densities of cluster sites can be created via methods outlined earlier, a high reaction rate per cc should result given a competitive power cell. The approach starts with creation of a micro-fiber felt sandwich structure. Palladium is then sputtered onto the Ni substrate prior to encapsulating it into the sandwich electrode configuration. Many local defects occur at interfaces in this configuration, giving a high volumetric density of potential cluster sites. This work is currently in progress, and preliminary results to data are encouraging.

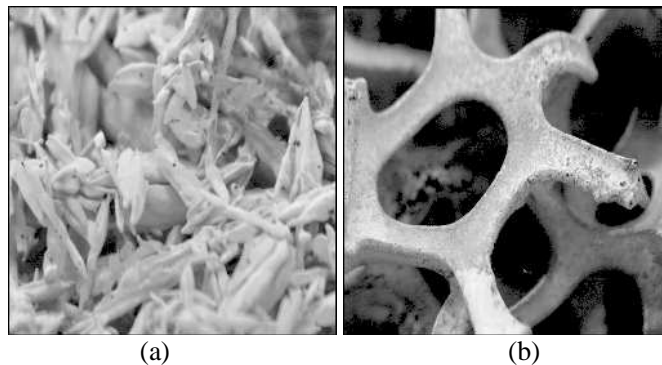


FIGURE 2 (a) Auger Scan of Ni Microfelt and (b) Ni foam electrodes [White color indicates Pd].

4. Observation of Defects and Ultra-High-Density Deuterium Cluster in Other Materials

Encouraged about the result [1, 2] that SQUID measurements confirmed the localization of more than 100 nuclei of hydrogen in a crystal defect within a palladium crystal, an estimation was given [5] how many such defects may be generated in a crystal. A density of such defects in crystals may well be more than 10^{19} cm^{-3} before the crystal is breaking. This is the experience from the property in silicon crystals where such densities of doped atoms are well known. Similar density of defects with voids has been produced in silicon too by very intense electron bombardment. [7, 8, 9, 10] If these voids are then in an average distance of 10 atoms in the crystals for laser fusion targets based on LiH or similar crystals at room temperature, the targets with a density of fusion fuel of 1000 times solid state density may be possible [b].

A necessary condition, however, is that the clusters in the crystal volume should have the density of 10^{24} cm^{-3} . These densities have been confirmed [3] from clusters which were produced in crystal defects at the surface of iron oxide by catalytic processes of inverted Rydberg states. These densities were proved from the Coulomb repulsion energy of deuterons in such states as time-of-flight measurements showed 630 eV w. This corresponds to a distance of the deuterons of 2.3 pm within the inverted Rydberg clusters. The repulsion process is given, when laser irradiation of 546 nm wave length removes the neutralizing electrons between the deuterons [3].

The mechanism of the electron emission by the laser radiation has been analyzed by inclusion of the correspondence principle of electromagnetic interaction [11]. A virtual quiver motion of the electrons in the quantum state in the inverted Rydberg cluster arrives at a quiver elongation of 2.3 pm

at a laser intensity of 1.01×10^{10} W/cm². This intensity was just measured as the lowest threshold [3] for the measurement of the 630 eV deuterons.

A further conclusion of this analysis is that the state of the deuterons in these clusters represents an effective Bose-Einstein condensation at room temperature. [12] A further result is for a hydrogen atom, the virtual quiver motion of the electron within the laser field with an elongation of the Bohr radius corresponds to the well known ionization energy of 13.6 eV. This energy has the unique value of $\alpha^2 mc^2/2$ expressed by the fine structure constant α and the rest mass energy of the electrons mc^2 with the electron mass m and the vacuum speed of light c .

5. Summary

It may be concluded that the state of the deuterium clusters with more than 100 deuterons measured with SQIDS in single crystal defects [1, 2] is similar to the ultra-density clusters [3]. These were measured by time-of-flight spectrometry during laser irradiation of surface defects which are considered as inverted Rydberg states D(-1). Following these exciting findings, new nano-manufacturing methods are now being explored to achieve larger packing fractions of these ultra-high-density deuterium cluster materials. Further, the extension of the technology to other materials, such as low Z materials, like Li and Be, is needed in order to reduce the cost and Bremsstrahlung losses. If these goals can be achieved, a remarkable new type of high performance non-cryogenic ICF target would become a reality.

References

- [1] A. Lipson, B.J. Heuser, C. Castanov, G. Miley, B. Lyakov, A. Mittin. Transport and magnetic anomalies below 70 K in a hydrogen cycles Pd foil with a thermally grown oxide, *Phys. Rev. B* 72 (21): 212507-10, 2005
- [2] G. H. Miley and X. Yang, (2009), Deuterium Cluster Target for Ultra-High Density Fusion, *Fusion Science and Technology*, 56 (1), 395-400
- [3] Shahriar Bardei, Patrick U. Andersson, Leif Holmlid. (2009) High-energy Coulomb explosions in ultra-dense deuterium: Time-of-flight-mass spectrometry with variable energy and flight length, *International Journal of Mass Spectrometry*, 282 (1-2), 70-76.
- [4] H. Hora, G.H. Miley. Maruhn-Greiner maximum from uranium fission for confirmation of low energy nuclear reactions LENR via a compound nucleus with double layer magic numbers. *Journal of Fusion Energy*. 26 (2007) 349-354 & 347.
- [5] L. Holmlid, H. Hora, G.H. Miley, X. Yang, (2009) Ultrahigh-density deuterium of Rydberg matter clusters for inertial confinement fusion targets. *Laser and Particle Beams* 27 529-532.
- [6] Patrick U.. Andersson, Leif Holmlid. Ultra-dense deuterium: a possible nuclear fuel for inertial confinement fusion (ICF). *Physics Letters A* doi:10.1016/j.physleta.2009.06.046.
- [7] H. Hora, Shift of Absorption of Evaporated Silicon Layers by Bombardment with 75 keV, *Naturwissenschaften* 48, 641 (1961)
- [8] H. Hora, Change of Silicon by Intensive Bombardment with 50 keV Electrons, *Zeitschrift f. angew. Phys.* 14, 9-12 (1962).
- [9] HORA, H. (1983). Stresses in silicon crystals from ion-implanted amorphous regions *Appl. Phys. A* 32, 1–5.
- [10] GOLDSMID, H.J., HORA, H. & PAUL, G.L. (1984). Anomalous heat conduction of ion-implanted amorphous layers in silicon crystals using a laser-probe technique. *Phys. Stat. Sol.* (a) 81, K127–K130.
- [11] H. Hora and P.H. Handel, New Experiments and theoretical development of the Quantum Modulation of Electrons (Schwarz-Hora effect), *Advances in Electronics and Electron Physics*, P.W. Hawkes ed. (Acad. Press, New York, 1987) Vol. 69, p.55-113., Chapter III.
- [12] Yeong E. Kim, Theory of Bose–Einstein condensation mechanism for deuteron-induced nuclear reactions in micro/nano-scale metal grains and particles, *Naturwissenschaften*. 96(7):803-11, 2009A reference